

IN THE SPECIFICATION

Please delete the entire section entitled "BRIEF SUMMARY OF THE INVENTION" beginning at column 2, line 53 and ending at column 4, line 33. In place of this deleted text, please add the following new text, which is consistent with the amended claims submitted below.

--An embodiment of the invention relates to a method for the liquefaction of a feed gas which comprises providing at least a portion of the total refrigeration required to cool and condense the feed gas by utilizing a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range, and a second refrigeration system which provides refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream. The first refrigeration system is operated by

(1) compressing a first gaseous refrigerant;

(2) cooling and at least partially condensing the resulting compressed refrigerant;

(3) reducing the pressure of the resulting at least partially condensed compressed refrigerant;

(4) vaporizing the resulting reduced-pressure refrigerant to provide refrigeration in the first temperature range and yield a vaporized refrigerant; and

(5) recirculating the vaporized refrigerant to provide the first gaseous refrigerant of (1).

At least a portion of the cooling in (2) is provided by indirect heat exchange with one or more additional vaporizing refrigerant streams provided by a third refrigeration system. The third refrigeration system may utilize a single component refrigerant or alternatively may utilize a mixed refrigerant comprising two or more components.

Another embodiment of the invention relates to a method for the liquefaction of a feed gas which comprises providing at least a portion of the total refrigeration required to cool and condense the feed gas by utilizing a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range, and a second refrigeration system which provides

refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream. The second recirculating refrigeration system is operated by

(1) compressing a second gaseous refrigerant to provide the pressurized gaseous refrigerant in (b);

(2) cooling the pressurized gaseous refrigerant to yield a cooled gaseous refrigerant;

(3) work expanding the cooled gaseous refrigerant to provide the cold refrigerant in (b);

(4) warming the cold refrigerant to provide refrigeration in the second temperature range; and

(5) recirculating the resulting warmed refrigerant to provide the second gaseous refrigerant of (1).

At least a portion of the cooling in (2) is provided by indirect heat exchange with one or more additional vaporizing refrigerants provided by a third refrigeration system.

The third refrigeration system may utilize a single component refrigerant or alternatively may utilize a mixed refrigerant which comprises two or more components.

A further embodiment of the invention relates to a method for the liquefaction of a feed gas which comprises providing at least a portion of the total refrigeration required to cool and condense the feed gas by utilizing a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range, a second refrigeration system which provides refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream. The first refrigerant system is operated by

(1) compressing a first gaseous refrigerant;

(2) cooling and partially condensing the resulting compressed refrigerant to yield a vapor refrigerant fraction and a liquid refrigerant fraction;

(3) further cooling and reducing the pressure of the liquid refrigerant fraction, and vaporizing the resulting liquid refrigerant fraction to provide refrigeration in the first temperature range and yield a first vaporized refrigerant;

(4) cooling and condensing the vapor refrigerant fraction, reducing the pressure of at least a portion of the resulting liquid, and vaporizing the

resulting liquid refrigerant fraction to provide additional refrigeration in the first temperature range and yield a second vaporized refrigerant; and

(5) combining the first and second vaporized refrigerants to provide the first gaseous refrigerant of (1).

The vaporization of the resulting liquid in (4) is effected at a pressure lower than the vaporization of the resulting liquid refrigerant fraction in (3), and the second vaporized refrigerant is compressed before combining with the first vaporized refrigerant.

Another embodiment of the invention includes a method for the liquefaction of a feed gas which comprises providing at least a portion of the total refrigeration required to cool and condense the feed gas by utilizing a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range, and a second refrigeration system which provides refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream. The second refrigeration system is operated by

(1) compressing a second gaseous refrigerant to provide the pressurized gaseous refrigerant in (b);

(2) cooling the pressurized gaseous refrigerant to yield a cooled gaseous refrigerant;

(3) work expanding the cooled gaseous refrigerant to provide the cold refrigerant in (b);

(4) warming the cold refrigerant to provide refrigeration in the second temperature range; and

(5) recirculating the resulting warmed refrigerant to provide the second gaseous refrigerant of (1).

The feed gas is natural gas, the resulting liquefied natural gas stream is flashed to lower pressure to yield a light flash vapor and a final liquid product, and the light flash vapor is used to provide the second gaseous refrigerant in the second refrigerant system.

Another embodiment of the invention relates to a method for the liquefaction of a feed gas which comprises providing at least a portion of the total refrigeration required to cool and condense the feed gas by utilizing a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range, and a second refrigeration system which provides

refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream. The second refrigeration system is operated by

(1) compressing a second gaseous refrigerant to provide the pressurized gaseous refrigerant in (b);

(2) cooling the pressurized gaseous refrigerant to yield a cooled gaseous refrigerant;

(3) work expanding the cooled gaseous refrigerant to provide the cold refrigerant in (b);

(4) warming the cold refrigerant to provide refrigeration in the second temperature range; and

(5) recirculating the resulting warmed refrigerant to provide the second gaseous refrigerant of (1).

At least a portion of the pressurized gaseous refrigerant in (2) is entirely cooled separately from cooling of the feed gas. All of the pressurized gaseous refrigerant may be cooled separately from cooling of the feed gas.

A portion of the pressurized gaseous refrigerant may be cooled by indirect heat exchange with the at least one recirculating refrigeration circuit of (a). The first refrigeration system may comprise a mixed component, pure component, and/or a cascaded vapor recompression refrigeration system.

Another embodiment of the invention includes an apparatus for the liquefaction of a feed gas comprising

(a) a first refrigeration system comprising at least one recirculating refrigeration circuit, wherein the first refrigeration system utilizes two or more refrigerant components and provides refrigeration in a first temperature range, wherein at least a portion of the first temperature range is between -40°C and -100°C ; and

(b) a second refrigeration system which provides refrigeration in a second temperature range by work expanding a pressurized gaseous refrigerant stream, wherein at least a portion of the second temperature range is below -100°C .

The first refrigeration system comprises

(1) compression means for comprising a first gaseous refrigerant;

(2) heat exchange means for cooling and at least partially condensing the resulting compressed refrigerant;

(3) means for reducing the pressure of the resulting at least partially condensed compressed refrigerant ;

(4) heat exchange means for vaporizing the resulting reduced-pressure refrigerant to provide refrigeration in the first temperature range and yield a vaporized refrigerant; and

(5) means for recirculating the vaporized refrigerant to provide the first gaseous refrigerant of (1).

The apparatus may comprise additional heat exchange means to provide at least a portion of the cooling of (2) by indirect heat exchange with one or more additional vaporizing refrigerant streams and a third refrigeration system to provide the one or more additional vaporizing refrigerant streams.

In this embodiment, the second refrigeration system comprises

(6) compression means for compressing a second gaseous refrigerant to provide the pressurized gaseous refrigerant;

(7) heat exchange means for cooling the pressurized gaseous refrigerant to yield a cooled gaseous refrigerant;

(8) expansion means for work expanding the cooled gaseous refrigerant to provide the cold refrigerant;

(9) heat exchange means for warming the cold refrigerant to provide refrigeration in the second temperature range; and

(10) means for recirculating the resulting warmed refrigerant to provide the second gaseous refrigerant of (6).

At least one of the heat exchange means in the first and second refrigeration systems of this embodiment may comprise a wound coil heat exchanger.

A final embodiment of the invention relates to an apparatus for the liquefaction of a feed gas comprising

(a) a first refrigeration system comprising at least one recirculating refrigeration circuit utilizing two or more refrigerant components and providing refrigeration in a first temperature range; and

(b) a second refrigeration system which provides refrigeration in a second temperature range having a lowest temperature less than the lowest temperature in the first temperature range.

The second refrigeration system comprises

(1) compression means for compressing the second gaseous refrigerant to provide the pressurized gaseous refrigerant;

(2) heat exchange means for entirely cooling at least a portion of the pressurized gaseous refrigerant separately from cooling of the feed gas to yield at least a portion of the cooled gaseous refrigerant;

(3) expansion means for work expanding the cooled gaseous refrigerant to provide the cold refrigerant;

(4) heat exchange means for warming the cold refrigerant to provide refrigeration in the second temperature range; and

(5) means for recirculating the resulting warmed refrigerant to provide the second gaseous refrigerant of (1).

In this embodiment, the heat exchange means of (2) may cool all of the pressurized gaseous refrigerant separately from cooling of the feed gas. The first refrigeration system may comprise

(A) compression means for compressing the first gaseous refrigerant;

(B) heat exchange means for cooling and at least partially condensing the resulting compressed refrigerant;

(C) pressure reducing means for reducing the pressure of the resulting at least partially condensed compressed refrigerant;

(D) heat exchange means for vaporizing the resulting reduced-pressure refrigerant to provide refrigeration in the first temperature range and yield the vaporized refrigerant; and

(E) means for recirculating the vaporized refrigerant to provide the first gaseous refrigerant of (A).

In this embodiment, at least a portion of the cooling in the heat exchanger of (2) may be provided by indirect heat exchange by warming the cold refrigerant in (4). At least one of the heat exchange means of the first and second refrigeration systems may comprise a wound coil heat exchanger.--

Please amend the paragraph beginning at column 7, line 58 (beginning with "A preferred embodiment . . .") through column 8, line 16, as follows:

--A preferred embodiment of the invention illustrated in Fig. 1. The process can be used to liquefy any feed gas stream, and preferably is used to liquefy natural gas as described below to illustrate the process. Natural gas is first cleaned and dried in pretreatment section 172 for the removal of acid gases such as CO₂ and H₂S along with other contaminants such as mercury. Pre-treated gas stream [steam] 100 enters heat exchanger 106, is cooled to a typical intermediate temperature of approximately -30°C, and cooled stream 102 flows into scrub column 108. The cooling in heat exchanger 106 is effected by the warming of mixed refrigerant stream 125 in the interior 109 of heat exchanger 106. The mixed refrigerant typically contains one or more hydrocarbons selected from methane, ethane, propane, i-butane, butane, and possibly i-pentane. Additionally, the refrigerant may contain other components such as nitrogen. In scrub column 108, the heavier components of the natural gas feed, for example pentane and heavier components, are removed. In the present examples the scrub column is shown with only a stripping section. In other instances a rectifying section with a condenser can be employed for removal of heavy contaminants such as benzene to very low levels. When very low levels of heavy components are required in the final LNG product, any suitable modification to scrub column 108 [110] can be made. For example, a heavier component such as butane may be used as the wash liquid.--

Please amend the paragraph beginning at column 8, line 17 (beginning with "Bottoms product 110 . . .") through column 8, line 44, as follows:

--Bottoms product 110 of the scrub column then enters fractionation section 112 where the heavy components are recovered as stream 114. The propane and lighter components in stream 118 pass through heat exchanger 106, where the stream is cooled to about -30°C, and recombined with the overhead product of the scrub column to form purified feed stream 120. Stream 120 is then further cooled in heat exchanger 106 [122] to a typical temperature of about -100°C by warming mixed refrigerant stream 125 [124]. The resulting cooled stream 126 is then further cooled to a temperature of about -166°C in heat exchanger 128. Refrigeration for cooling in heat

exchanger 128 is provided by cold refrigerant fluid stream 130 from turbo-expander 166. This fluid, preferably nitrogen, is predominately vapor containing less than 20% liquid and is at a typical pressure of about 11 bara (all pressures herein are absolute pressures) and a typical temperature of about -168°C. Further cooled stream 132 can be flashed adiabatically to a pressure of about 1.05 bara across throttling valve 134. Alternatively, pressure of further cooled stream 132 could be reduced across a work expander. The liquefied gas then flows into separator or storage tank 136 and the final LNG product is withdrawn as stream 142. In some cases, depending on the natural gas composition and the temperature exiting heat exchanger 128, a significant quantity of light gas is evolved as stream 138 after the flash across valve 134. This gas can be warmed in heat exchangers 128 and 150 and compressed to a pressure sufficient for use as fuel gas in the LNG facility.--

Please amend the paragraph beginning at column 8, line 45 (beginning with "Refrigeration to cool . . . ") through column 9, line 5, as follows:

--Refrigeration to cool the natural gas from ambient temperature to a temperature of about -100°C is provided by a multi-component refrigeration loop as mentioned above. Stream 146 is the high pressure mixed refrigerant which enters heat exchanger 106 at ambient temperature and a typical pressure of about 38 bara. The refrigerant is cooled to a temperature of about -100°C in heat exchanger [exchangers] 106 [and 122], exiting as stream 148. Stream 148 is divided into two portions in this embodiment. A smaller portion, typically about 4%, is reduced in pressure adiabatically to about 10 bara and is introduced as stream 149 into heat exchanger 150 to provide supplemental refrigeration as described below. The major portion of the refrigerant as stream 125 [124] is also reduced in pressure adiabatically to a typical pressure of about 10 bara and is introduced to the cold end of heat exchanger 106. The refrigerant flows downward and vaporizes in interior 109 of heat exchanger 106 and leaves at slightly below ambient temperature as stream 152. Stream 152 is then re-combined with minor stream 154 which was vaporized and warmed to near ambient temperature in heat exchanger 150. The combined low pressure stream 156 is then compressed in multi-stage

intercooled compressor 158 back to the final pressure of about 38 bara. Liquid can be formed in the intercooler of the compressor, and this liquid is separated and recombined with the main stream 160 exiting final stage of compression. The combined stream is then cooled back to ambient temperature to yield stream 146.--

Please amend the paragraph beginning at column 11, line 8 (beginning with "The invention described . . . ") through column 11, line 18, as follows:

--The invention described above in the embodiments illustrated by Figs. 1-9 can utilize any of a wide variety of heat exchange devices in the refrigeration circuits including wound coil, plate-fin, shell and tube, and kettle type heat exchangers. Combinations of these types of heat exchangers can be used depending upon specific applications. For example in Fig. 2, all four heat exchangers 206 [106], 222 [122], 228 [128], and 250 [150] can be wound coil exchangers. Alternatively, heat exchangers 206 [106], 222 [122], and 228 [128] can be wound coil exchangers and heat exchanger 250 [150] can be a plate and fin type exchanger as utilized in Fig. 1.--

Please amend the paragraph beginning at column 11, line 49 (beginning with "Pretreated gas 100 . . . ") through column 11, line 53, as follows:

--Pre-treated gas 100 enters [enter] first heat exchanger 106 and is cooled to a temperature of -31°C before entering scrub column 108 as stream 102. The cooling is effected by the warming of mixed refrigerant stream 125 [109], which has a flow of 554,425 kg-mole/hr and the following composition:--

Please amend the paragraph beginning at column 12, line 6 (beginning with "Stream 120 is . . . ") through column 11, line 19, as follows:

--Stream 120 is further cooled in heat exchanger 106 [122] to a temperature of -102.4°C by warming mixed refrigerant stream 125 [124] which enters heat exchanger 106 [122] at a temperature of -104.0°C. The resulting stream 126 [128] is then further cooled to a temperature of -165.7°C in heat exchanger 128. Refrigeration for cooling in heat exchanger 128 is provided by

pure nitrogen stream 130 exiting turbo-expander 166 at -168.0°C with a liquid fraction of 2.0%. The resulting LNG stream 132 is then flashed adiabatically to its bubble point pressure of 1.05 bara across valve 134. The LNG then enters separator 136 with the final LNG product exiting as stream 142. In this example, no light gas 138 is evolved after the flash across valve 134, and flash gas recovery compressor 140 is not required.--

Please amend the paragraph beginning at column 12, line 20 (beginning with "Refrigeration to cool . . . ") through column 12, line 44, as follows:

--Refrigeration to cool the natural gas from ambient temperature to a temperature of -102.4°C is provided by a multi-component refrigeration loop as mentioned above. Stream 146 is the high pressure mixed refrigerant which enters heat exchanger 106 at a temperature of 32°C and a pressure of 38.6 bara. It is then cooled to a temperature of -102.4°C in heat exchanger [exchangers] 106 [and 122], exiting as stream 148 at a pressure of 34.5 bara. Stream 148 is then divided into two portions. A smaller portion, 4.1%, is reduced in pressure adiabatically to 9.8 bara and introduced as stream 149 into heat exchanger 150 to provide supplemental refrigeration. The major portion [124] of the mixed refrigerant is also flashed adiabatically to a pressure of 9.8 bara and introduced as stream 125 [124] into the cold end of heat exchanger 106 [122]. Stream 125 [124] is warmed and vaporized in heat exchanger [exchangers] 106 [and 122], finally exiting heat exchanger 106 at 29°C and 9.3 bara as stream 152. Stream 152 is then recombined with the minor portion of the mixed refrigerant as stream 154 which has been vaporized and warmed to 29°C in heat exchanger 150. The combined low pressure stream 156 is then compressed in 2-stage intercooled compressor 158 to the final pressure of 34.5 bara. Liquid is formed in the intercooler of the compressor, and this liquid is recombined with the main flow 160 exiting the final compressor stage. The liquid flow is 4440 kg-mole/hr.--